By Edward J. Kennedy, K3NS, and John Heckscher

The High Frequency Active Auroral Research Program

High-power HAARPing around in Alaska

During a recent public open house at a new government facility in Gakona, Alaska, a visiting ham was overheard to say, "this is a ham's dream station." The visitor, a KL7 from Anchorage, was referring to the antenna array being constructed for the High Frequency Active Auroral Research Program (HAARP). The array, together with its associated transmitters—called the Ionospheric Research Instrument (IRI)—is being constructed to play an integral role in an area of physics called active ionospheric research.

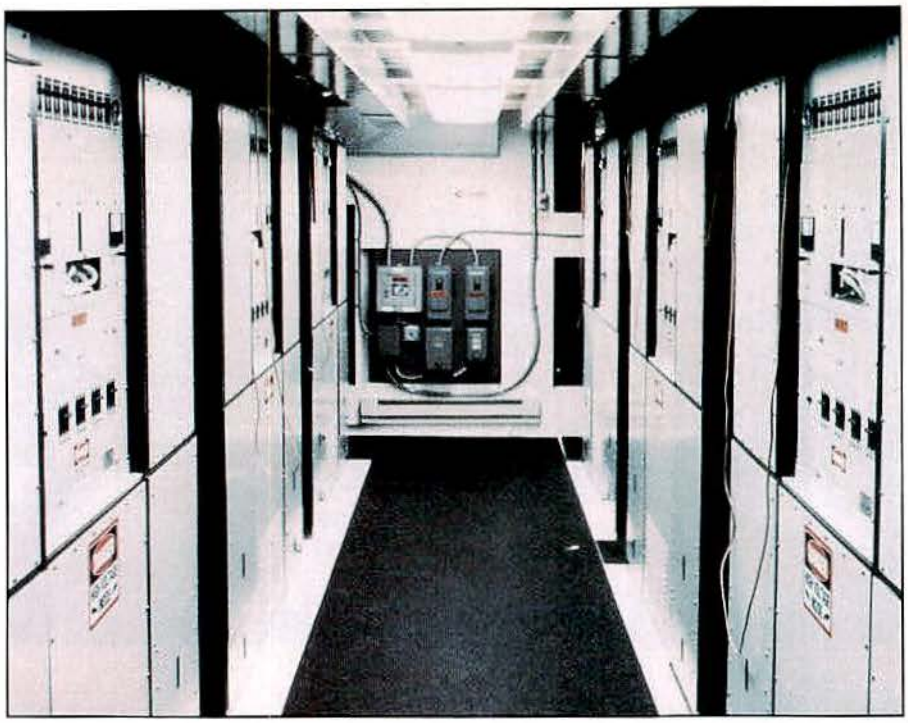
The ionosphere, which extends from about 35 miles above the Earth's surface to beyond 500 miles above it, is responsible for long-range communication in the high frequency (HF) bands through sky-wave propagation, a process that is well known to radio amateurs. The ionosphere is created and continually replenished through the action of the sun's radiation interacting with rarefied gases such as oxygen and nitrogen. Sudden variations in the sun's radiation can dramatically affect the performance of communication links—often negatively—by distorting and absorbing signals that pass through it. Severe geomagnetic storms can cause radio blackouts in the HF bands and can affect even satellite signals at much higher frequencies that must pass through this ionized medium.

Through the years, ionospheric research has attempted to improve our understanding of the physical processes that occur in this region of the Earth's atmosphere. Radio amateurs were among the first to discover the broad range of effects on communications applications. To a large degree, our ability to predict ionospheric effects is based on models derived from long-term observations of the performance of various communication links. Active ionospheric research such as that planned under the HAARP program, on the other hand, is aimed at studying primary physical processes that occur in the ionosphere. Ultimately, this research will lead to a more broadly based fundamental understanding of ionospheric physics and to better predictive performance.

Program Schedule

The HAARP program began in 1990 with an initial study effort to determine the feasibility of building a much more versatile ionospheric research facility than existed at the time. Three companies participated in that effort and, following an open competition, a contract was awarded in 1992 to build the IRI, following completion of the environmental impact process (EIP). The contract specified that a "developmental prototype" (DP) be constructed initially to evaluate and prove the engineering design before further construction could take place. The DP, completed in December 1994, has been undergoing intermittent testing since it was put into service. The DP consists of 48 antenna elements arranged in eight rows of six columns. There are only enough transmitters to drive 18 of these elements, however, so that the active portion of this array is six rows of three columns.

If the DP is shown to perform according to specification, the first phase of expansion will probably complete the transmitter complement to feed the existing 48 antenna elements, resulting in an array with a total transmitter power of 960 kW. Additional expansion is planned in two phases, one end-



Interior view of a transmitter shelter. Each shelter houses six transmitter cabinets, with three on each wall. Each cabinet is connected to a crossed-dipole pair in the antenna array. The transmitters are air-cooled through ductwork in the floor and ceiling.

ing at the 108-element (2.16-megawatt [MW]) size and the final IRI at the 180-element (3.6-MW) size.

The title photo shows the HAARP developmental prototype antenna array of 48 crossed-dipole antenna elements mounted on 65-foot towers. The mountains in the background are in the Wrangle–Mount St Elias Park.

The HAARP Facility

The HAARP facility will consist of two essential, but quite different sets of equipment:

- The IRI, which is the most visible aspect of the site, and
- A suite of sensitive scientific or "diagnostic" instruments.

The purpose of the IRI is to introduce energy into a selected layer of the ionosphere directly over the site through a process of high frequency "heating," mimicking in a small way and over a limited area, the action of the sun. This energy is, relatively speaking, quite small compared to what the sun provides. During ionospheric storminess, for example, the IRI is ineffective.

The diagnostic instruments, some located on site and others at distant locations, provide the ability to observe the effects resulting from the IRI heating on a truly detailed scale. The ability to control the amount and duration of energy introduced into the layer by the IRI allows direct correlation with the diagnostic observations.

Primary power to operate the HAARP equipment will be generated locally using diesel-powered generators that will be located in a separate building. The site will also have an aircraft-detection radar installed to ensure that all appropriate transmitters are shut down whenever an aircraft is in the area.

Alaska is an ideal location for a facility such as HAARP because, over a period of time, the overhead ionosphere can range from near mid-latitude to auroral to polar, depending on the Sun's activity; this allows a broad assortment of research opportunities.

The Gakona site (see the map) was one of two candidates studied during the EIP that met the scientific requirements for geographic location. The site is approximately 160 miles from both Anchorage and Fairbanks in east-central Alaska.

Technical Details of the IRI

To introduce energy into the ionosphere, it is necessary to transmit signals at a frequency that interacts with the types of particles present at that altitude. In the ionosphere, both electrons and protons exist as a result of ionization by the sun's ultraviolet radiation. When an electromagnetic signal enters this region, part of its energy is converted to particle motion as kinetic energy. This conversion primarily affects the electrons and is strongly dependent on the frequency of the incoming signal. Frequencies at the low end of the HF band interact with the lower D and E layers; frequencies above 5 MHz usually interact at higher altitudes with the F layer. Any level of incoming signal (even QRP operation!) will give rise to this energy transfer.

The earliest indication of ionospheric "modification" was the modulation of one European AM broadcast station by the strong signals of another, which was observed early in this century—the so-called "Luxembourg effect." Experience has shown that power levels at or above those commonly used for international broadcast stations can produce detectable ionospheric modification. There are currently several facilities throughout the world constructed to perform active ionospheric research, all operating with 1 MW or higher power output.

The HAARP IRI is a rectangular planar array of horizontally polarized antenna elements covering the frequency range of 2.8 to 10 MHz. Each element is completely controllable in amplitude and phase, to permit the greatest flexibility in antenna beam formation. The antennas consist of two pairs of crossed dipoles, one pair for low band operation and the other for the high band. A wire mesh ground screen is located under the antenna elements at a height of 15 feet above the ground. The antennas are located at a height above the ground screen that produces a single, overhead radiation lobe.

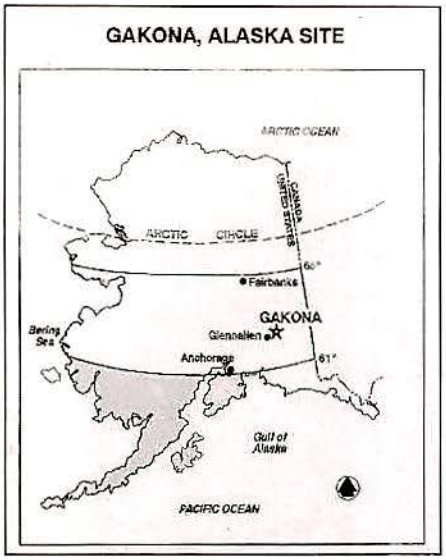
The antenna elements making up a crossed dipole pair are aligned approximately north-south (N-S) and east-west (E-W). An antenna matching unit (AMU) is located at each antenna feed point to improve the SWR and efficiency, and an open air balun is used to convert from coaxial cable to balanced feed. High-vacuum antenna switches are located in the balun boxes to select the appropriate antenna element.

There is one transmitter dedicated to each of the dipoles in a crossed dipole pair, so that each element (or tower) of the array is assigned two transmitters—one for its N-S antenna and one for its E-W antenna. Environmentally controlled trailers located under the ground screen each contain 12 transmitters and their associated controlling and cooling equipment.

To achieve the highest quality scientific results, the transmitters used in the HAARP array must meet stringent technical specifications. Each transmitter produces a maximum power output of 10 kW. The power must be controllable and remain linear over a 60-dB range. To achieve this, a design using two 4CX10,000 tubes in push-pull was chosen. These air-cooled tubes, which operate in Class AB to produce the required linearity, are driven by a 1-kW solid-state amplifier. For low-power operation, the tubes can be bypassed and the antenna fed directly from the driver stage. The transmitter low-power input circuitry contains a digitally controlled phase shifter. Each transmitter in the array can be set to a specific amplitude and phase, in order to produce an arbitrarily shaped antenna beam. The beam can be positioned anywhere within 30° of the vertical.

Each transmitter can be amplitude, frequency or phase modulated. Although the specifications do not require SSB modulation, the linearity of the whole amplifier chain is so good that during a recent emergency communication test, the IRI array was operated successfully using a TS-440 operating in the USB mode as the input signal source.

Early in the program, we realized that the high powers associated with ionospheric



The HAARP transmitter site is at Gakona, in Alaska.

research would require a transmitter design that is "clean" in other respects as well. As a result, the IRI transmitters contain a unique coaxial TVI filter as the last element in the circuit before the transmission line. The combination of this filter along with other aspects of the circuit design results in a transmitter that produces extraordinarily low harmonic and spurious signals. In fact, the spurious and harmonic frequencies produced by the entire IRI, when operating at full power, will be lower than those of commercially built Amateur Radio linear amplifiers that are in compliance with FCC Part 97 rules.

The entire IRI is controlled remotely over a fiber-optic data link from a single workstation. The workstation permits the operator to set up a specific experiment off line and run it when all of the diagnostic instruments are ready to observe the results.

Electromagnetic Compatibility

In spite of all of the measures taken to minimize interference from the IRI, there is no escaping the fact that, if propagation conditions are right, HAARP could possibly interfere with other users of the HF spectrum. HAARP's authority to transmit is derived from the National Telecommunications and Information Administration (NTIA), part of the Department of Commerce. The NTIA, the government counterpart to the FCC, has restricted HAARP to specific frequency ranges (none of which are amateur!), and the environmental impact statement (EIS) asserts that HAARP will operate on a voluntary noninterference basis. This means that all other occupants of the HF spectrum have priority, and that HAARP must cede frequencies to existing users. Furthermore, the results of the EIP require HAARP to set up a Radio Frequency Interference (RFI) Resolution Advisory Committee with a regular meeting schedule (The ARRL is represented on this committee.) In addition, a computer-controlled spectrum monitor is in continuous operation at the site to document transmission times and frequencies and to determine frequencies that are in use, not only for the primary IRI transmission, but for any harmonic up to 1 GHz. Finally, there is a dedicated interference reporting hot line (907-822-5497) for the reporting of suspected HAARP radio interference. So far—during the seven test periods conducted since December 1994 at power levels up to 360 kW—there has not been a single report on this hot line that was confirmed as HAARP interference. (The answering machine tape tends to fill up, however, during the extended periods when HAARP is shut down!).

For Further Information

Although program management of HAARP has been assigned to the Air Force and Navy, the program is completely unclassified. The facility that is being built is identical to the facility described in the EIS.

The HAARP program maintains a World Wide Web site at **http://server5550.itd.nrl.navy.mil/haarp.html** (the material is updated regularly and often). There is a special link on the home page that will lead you to sites for additional information about the ionosphere and to other institutions that are conducting research of a related nature. We plan to move the server for this site to the HAARP facility in Alaska sometime during 1996. By doing so, it will be possible to present real-time ionospheric data to the Internet as it is being collected at the site. There are even plans to print special HAARP QSL cards, although we hope no one ever claims one.

Edward Kennedy, K3NS, of 4555 Overlook Ave, SW, Washington, DC 20375, holds BEE and MEE degrees from The Catholic University of America and works for the Naval Research Laboratory in Washington, DC. Ed serves as the technical representative to the contracting officer for the HAARP program. Ed has been a ham for 37 years and has been active in contesting, DX and satellites. He formerly held the call signs K4VGC and WA3RZS.

John Heckscher holds a BSEE degree from Princeton and an MSEE from The Johns Hopkins University. He has been with the Air Force's research laboratories at Hanscom AFB, Massachusetts, since 1959, first as a USAF officer, then as a civilian research physicist, a section supervisor, and currently as HAARP Program Manager. His past interests have included radio propagation, antennas, and the characteristics of radio noise and its sources.

How HAARP might benefit Amateur Radio

Eric Nashlund, NL7ZW, is the ARRL's representative on the HAARP Radio Frequency Interference Resolution Advisory Committee mentioned in this article. He was invited to serve on the committee by Alaska's former Section Manager Larry Flanagan, NL7XG. Here are some of Eric's comments on how the HAARP project might affect Amateur Radio, from the two perspectives of being a committee member and also a nearby neighbor of the project's transmitter site.—*Ed.*

Professor Michael Kelley, of Cornell University's School of Electrical Engineering, told me that the heated cone in the ionosphere created by HAARP transmission should be much more stable than the aurora, and should also have fewer problems of Doppler shift than does the aurora. This suggests to me that amateurs could use HAARP's ionization cones much as they use the aurora for extended-range propagation at VHF and higher frequencies.

There is another manner in which HAARP might be beneficial to hams. The affected region created by HAARP will slowly move away from the vertical under the influence of high-altitude winds. The beam tends to follow this drift because of changes in refractivity. At some point, the refractivity is insufficient to keep the beam "attached" and the heated volume breaks away, allowing the beam to move back to the vertical. The heated volume now moves away from the facility, dissipating as it does so, drifting westward prior to midnight local time or eastward after midnight. The rate of drift of these clouds can vary from about 200 to about 4500 mph. Inasmuch as these clouds of modified electron density track eastward and westward of the magnetic North Pole, they might prove to be useful to hams in Canada, the northern tier of states of the US, and nearby northern countries, for VHF scatter propagation. Professor Kelley suggested that a joint effort between HAARP personnel and the ham community could test the utility of such ionized clouds for 6-meter propagation.

Some hams are concerned with the possibility that HAARP might cause widespread interference to amateurs. Last year, a local shortwave listener contacted me to help him check HAARP transmissions to see if they appeared to be as clean as the US Air Force claimed.

We started with a Sangean ATS-803A scanning receiver at his home (about 15 miles east of the HAARP site) and a Yaesu FRG-7 at my home (45 miles south of the site), with both of us using low dipoles. Then, in order to observe the waveform of the signal, my friend bought a surplus R-392 receiver and we connected its IF output to a Tektronix oscilloscope of mine.

We waited for the next transmitting tests to begin, with the scanning receiver set to alert us to their onset. When the transmission began, we could copy their fundamental signal at 40 to 60 dB over S9 on the receiver's S-meter. When we tuned the R-392 to the fundamental frequency and observed the signal waveform on the oscilloscope, we saw what appeared to be a perfect sine wave, with no visible harmonic content.

We then tuned our other receivers to the frequencies of the second through the fourth harmonics and could not detect any harmonic signals at all. It's obvious that the 80-dB spurious emission suppression claimed by the Air Force is being met!—*Eric Nashlund, NL7ZW*